

## HINS Linac Front End Superconducting Cavity Magnetic Field Requirements

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Magnetic field inside a cryostat with accelerating cavities can be of an external or internal origin. Examples of the external fields are earth magnetic field modified by structural elements around the cryostat, magnetic field generated by equipment installed in the vicinity and by electric power distribution lines. Usually the external field is of the order of 100  $\mu\text{T}$ , but can be significantly higher in some cases; direction of this field is difficult to predict. Vacuum vessel of a cryostat can also be a source of magnetic field, which can be quite significant if the cryostat material choice was not address carefully. To get rid of the external magnetic field, a magnetic shielding is to be installed outside or inside the cryostat. In some cases, demagnetization of the cryostat's vacuum vessel is also required.

A source of the magnetic field can also be inside the cryostat, e.g.

- remanent magnetic induction in steel (or stainless steel) structural elements,
- remanent magnetic induction in steel flux returns of focusing elements,
- stray field of these focusing elements (solenoids or quadrupoles),
- persistent currents in superconducting materials of the focusing elements,
- stray magnetic field of other electromagnetic devices inside the cryostat.

Magnetic field must be as low as possible in the areas where superconducting RF structures are installed. RF surface resistance of a superconductor depends on the magnetic field. Penetration of flux lines through the surface of a Type II superconductor, like Niobium (Nb), results in the appearance of normal conducting areas within the surface with corresponding increase of the average surface resistance. At 325 MHz, the growth rate of the surface resistance of pure Nb due to trapped magnetic field is  $dR_s/dB = 1.5 \text{ n}\Omega/\mu\text{T}$ .

The increase of the surface resistance results in the corresponding drop of the quality factor of accelerating cavities. A criterion for evaluation of the allowed magnetic field is the drop of the cavity quality factor by factor of two.

At high frequency, the surface resistance  $R_s$  of the superconductor can be found as a sum  $R_s = R_{BCS} + R_{res}$ , where BCS part  $R_{BCS}$  depends on temperature and the residual resistance  $R_{res}$  does not.

At 4.5 K and 325 MHz, the surface resistance  $R_s$  of Nb with RRR = 300 is  $\sim 50$  n $\Omega$ . So, with the allowed two-fold quality factor drop, corresponding to the surface resistance increase of 50 n $\Omega$ ,  $50/1.5 = 33$   $\mu$ T field is allowed. In this case, the total RF CW power loss on the cavity walls of the SSR-1 section cavity is about 10 W.

At 2K,  $R_{BCS} = 0.7$  n $\Omega$ , so surface resistance  $R_s$  is defined mainly by residual resistance  $R_{res}$  and expected to be about 20 n $\Omega$ . So,  $20/1.5 = 13$   $\mu$ T field is allowed.

The allowed magnetic field is an average normal component of the field on the surface of the cavity. If the field is parallel to the walls at some parts of the cavity or non-uniform along the walls, an appropriate adjustment can be made. This field also depends on thermodynamic history of the cavities.

The requirements stated above were derived for cavities in the normal state, cooled down to the temperature just above the transition, with no adjustment for the field direction or non-uniformity. If a cavity was cooled down with the field limit mentioned above and then turned superconducting, higher field on the surface of the cavity can be allowed because of the shielding effect of the superconductor (Meissner effect is still working for the Type II superconductor at low field level). If part of the cavity surface “quenches” (turns normal), additional number of flux tubes penetrates the cavity walls in the area of the quench and certain drop of the quality factor (through average surface resistance growth) is to be expected. Because currents in the end walls of the accelerating spoke cavities of the superconducting sections are 1.5-2 times smaller than currents in the spoke, the magnetic field in the area of the end walls can be 2-4 times higher (to allow generation of the same power). On the surface of the spokes of the cavities, the magnetic field requirements should be as they were in the case of cooled cavities just before transition to the superconducting stage.

Theoretically, if no quenching occurs in the cold superconducting cavity, the magnetic field outside the cavity can be as high as  $H_{C1}$  limit, which for Nb is  $\sim 170$  mT. Practically, we will consider this field limit as unacceptable.

To summarize this analysis, a desirable limit of magnetic field on the walls of superconducting cavities can be set at the level of  $\sim 10$   $\mu$ T with some reserve, which is due to direction and spatial distribution of the magnetic field. If no 2K operation is expected, this limit can be  $\sim 30$   $\mu$ T.